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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
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SUMMARY PAGE

THE PROBLEM

Since its inception, the principal goal of the Navy's Hearing Conservation Program has been the gathering of accurate and reliable hearing threshold data primarily by way of group audiometric testing procedures. Past attempts to establish procedures for group testing have been considered inadequate, as has the present-day application of group self-recording audiometry. There has been growing evidence from occupational and environmental health surveys at shipyards and naval air rework facilities that a large percentage of the audiograms currently being obtained on group units are invalid, either because the technician did not, or could not, monitor the test properly or the subject did not, or could not, respond properly. Recently developed microprocessor-controlled audiometers may provide a means to minimize or eliminate some of these problems.

FINDINGS

A laboratory and field assessment of several recently developed microprocessor-controlled audiometers (MCAs) indicates that they produce, within acceptable variation, hearing threshold levels comparable to those obtained with manual audiometry and within similar timeframes. The new generation of audiometers makes it possible for any threshold-seeking procedure to be programmed and standardized at all test locations. Moreover, these automated hearing test instruments can also be programmed to provide fault detection algorithms which make it difficult for individuals to falsify the audiometric data. Tentative performance specifications have been identified for the development of an MCA for use in Navy hearing conservation programs.

Microprocessor-controlled audiometers have the capability of interfacing with a larger computer either directly or through the generation of on-board data tapes. Such interfacing of MCAs with a regional or central computer facility would aid significantly in the administrative surveillance of hearing threshold data as well as in the execution and management of many other potential tasks within the purview of the hearing conservation program.

RECOMMENDATION

Field testing of a group microprocessor-controlled audiometer is recommended prior to establishing final Navy performance specifications for such an instrument.

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INTRODUCTION

If the Navy is to realize any success in the implementation of the audiometric monitoring aspect of its hearing conservation program, it is imperative that an automated device capable of reliably testing the hearing of large groups of individuals be developed. The assessment of selected automated hearing test equipment described in this report is considered to be an essential first step in development of such a device. The consequences of not having equipment with such capability can be costly both in human and economic terms. This fact has been demonstrated forcefully in recent years in our naval shipyards where hearing compensation claims paid to date have amounted to over $114,000,000 (1). The human cost is impossible to assess.

BACKGROUND

Some twenty-three years have elapsed since the Committee on Hearing Bioacoustics and Biomechanics (CHABA), as part of its 1955 annual meeting, conducted a symposium on "Problems in Military Audiometry." At that time, the Navy, the Army, and the Air Force were working to establish programs designed to test more accurately and efficiently the hearing of candidates for military service and the hearing of personnel exposed to high-intensity noises of various types. A CHABA report (2) and a subsequently published article (3) did much to facilitate the understanding and discussion of many of the practical problems found in military audiometry.

To assist in defining the unresolved issues related to audiometry and audiometers, the CHABA Council requested the executive secretary of CHABA to prepare a summary statement of the purposes and objectives of audiometry and also to make certain recommendations in regard to the testing of hearing in the Armed Forces. An official expression of opinion by the CHABA Council was published as part of the aforementioned article (3). The Council recommended that the administration of pure tone audiometry by a rapid means be instituted so that the hearing of personnel could be checked easily, or 'monitored,' as a routine procedure. The term 'monitoring audiometry' was introduced to designate an intermediate form of audiometric testing which is more elaborate than 'screening audiometry' but less elaborate than 'diagnostic audiometry.' As pointed out in the CHABA statement:

> The objectives of 'monitoring audiometry' are twofold: one is to establish the state of hearing of a relatively large number of individuals to provide reference audiograms from which subsequent changes in their hearing are measured. The reference audiograms, particularly if they are pre-employment or so-called preplacement audiograms, may be used to determine subsequent liability for later changes in hearing in connection with workman's compensation. Its other objective is to detect changes in the hearing of individuals, relative to their reference audiograms before the hearing losses become a practical handicap. Monitoring audiometry thus gives warning in time for instituting effective protective measures, such as the reduction of the noise itself, the reduction of the noise exposure to the individual or the use of individual protective measures (3).

The Council felt that although 'monitoring audiometry' had evolved in industrial hearing conservation programs, it could be easily adapted to the needs of the armed services. In its summary statement, the Council pointed out that specifications for experimental monitoring audiometers could be developed after the three services reached certain basic decisions regarding the audiometric standards that their personnel must meet.

Since its inception, the principal goal of the Navy's Hearing Conservation Program has been the gathering of accurate and reliable threshold information by way of group testing procedures. In 1962, self-recording group audiometers were introduced into the Navy primarily for conducting monitoring hearing tests for hearing conservation programs. Since then, their use has been widened to include hearing tests as part of physical examinations and to establish baseline hearing threshold levels (HTLs) for hearing conservation purposes. Currently there are over 50 self-recording group audiometers (comprising some 412 channels) in use at naval activities.

Unfortunately, many of the problems in military monitoring audiometry discussed by CHABA in 1955 persist today. Attempts to establish procedures for group testing have been considered inadequate (4), as has the present-day application of group self-recording audiometry. To illustrate the latter case, there has been growing evidence from occupational and environmental health surveys at shipyards and naval air rework facilities that threshold data currently being obtained on self-recording group audiometers do not agree with published data concerning the validity and reliability of self-recording audiometry (5). That is, a large percentage of the audiograms currently being obtained on such units are invalid, either because the technician did not, or could not, monitor the test properly or the subject did not, or could not, respond properly. To further underscore the present state of self-recording group audiometry, the Bureau of Medicine and Surgery recently directed activities to refrain from purchasing self-recording audiometers and to limit group testing to four subjects (6). Listed below are several of the current problems associated with group audiometry, and to a somewhat lesser extent, individual self-recording audiometry:

- The current self-recording test procedure lends itself to the falsification of findings by even the least sophisticated individual.

- The audiometric record card of the self-recording audiometer is often not readable and/or is open to misinterpretation.

- Equipment operation by uncertified technicians is commonplace.

- Even with well-trained audiometric technicians currently available through Navy training programs, the present group self-recording test situation is difficult to monitor properly.

- The technician must remain at the instrument for maximum test reliability to be achieved.

- When data are transferred to forms from the audiometric record cards, there is the possibility of incorrect values being recorded.

- The storage of audiometric data in individual medical records makes it impossible to efficiently retrieve information for use in making medical management decisions or for conducting large scale statistical studies.

Over the years there have been several attempts to develop automated group hearing test systems--instruments that would be immune to some of the problems mentioned above. In 1968, Campbell and Moulin (7) conducted research on up-and-down threshold tracking procedures utilizing a manual audiometer interfaced with recycling timers to regulate the duration and inter-trial intervals. Later, Campbell (8) advanced the instrumentation to include the use of a mini-computer. He reported a high correlation between computer-determined thresholds and thresholds determined by audiologists. In 1975, Meyer, Sutherland, and Brogan (9) described the development of an audiometric computer that utilized a tone count threshold technique and employed a modified Hughson-Westlake procedure (10). Subsequent testing with the tone count audiometric computer produced HTLs comparable to those obtained with group audiometers and to those obtained with manual audiometers for hearing conservation and physical standards purposes (11).

With the recent advent of digital microprocessors, the technology is now available which will enable the long-desired implementation of accurate and reliable automated group hearing testing. In addition, the various audiometric data acquisition, storage, and retrieval options available with automated hearing test devices can provide the means by which a standardized approach to data management for hearing conservation can be realized. Individual or group audiometers based on digital microprocessors make it possible for any one of a number of threshold-seeking procedures to be programmed and standardized at all test locations. Such devices can be programmed to provide fault-detection algorithms which will make it difficult for individuals to falsify the audiometric data, thereby enabling technicians to monitor a large number of testing stations. Because the data obtained with these devices are already in digital form, this output can be readily stored on digital devices (tape, disk, etc.), placed in alpha-numeric format on data storage sheets, and, ultimately, transferred over digital data lines to a centralized computer facility. The proper interfacing of such systems with a regional or central computer facility could provide an efficient means for scheduling hearing tests, and could aid in the administrative surveillance of data as well as in the execution of many other potential tasks within the purview of a hearing conservation program. The devices can also be programmed to perform data analysis on current HTLs, define significant threshold shifts from the baseline audiometric test, and compute any other parameter deemed necessary by the user (e.g., pure tone averages).

With the preceding capabilities in mind, the purpose of the present investigation was twofold: 1) to assess several currently available automated hearing test instruments; and 2) to describe tentative performance requirements for the development of such a device for use in Navy hearing conservation programs.

PROCEDURE

Information covering general features and technical specifications was assembled on microprocessor-controlled audiometers from the following eight manufacturers:

Maico Hearing Instruments, Inc.
Tracor, Inc.
Environmental Technology Corporation
Audiometer Corporation of America
Demlar Medical, Inc.
Monitor, Inc.
Audio-Medical Systems, Inc.
Dana Japan Company, Ltd.

After a review of the features and specifications, invitations were extended to all but the latter two manufacturers to demonstrate their systems at the Naval Aerospace Medical Research Laboratory (NAMRL), Pensacola. The only two group audiometric systems that were demonstrated (by Demlar Medical, Inc. and Monitor, Inc.) were insufficiently developed to permit a detailed assessment. The microprocessor-controlled audiometers (MCAs) demonstrated by the four remaining manufacturers were subsequently acquired for detailed assessment. The instruments and manufacturers were:

MA26, Maico Hearing Instruments, Inc.
RA 410, Tracor, Inc.
G.R.S.-1, Environmental Technology Corporation (ETC)
500 I, Audiometer Corporation of America (ACA)

Photographs of each of the above four MCAs are shown in Figures 1-4, and the dimensions and weight of each unit are shown in Figure 5. An understanding of the layout of control and display components and the overall physical characteristics of the different instruments can be gained through study of these figures. Further details on other characteristics of the instruments are contained in Appendices A through C. Features and specifications of the two systems not included in this assessment (from Audio-Medical Systems, Inc. and Dana Japan Co., LTD) are shown in Appendix D.

Exploratory laboratory assessments were conducted on the four production model automated test instruments mentioned above. In addition, the ETC instrument underwent field evaluation at the Naval Aerospace Regional Medical Center Branch Clinic, Pensacola, and an ETC group unit (8-man) was observed in operation at the Baltimore Armed Forces Entrance and Examining Station (AFEES).

Laboratory assessment of the four devices consisted of the following:

- A rating of various general features of the devices as well as features relating to repair, maintenance, and calibration.

- A comparison between automated and manual testing in relation to test duration and HTL agreement.

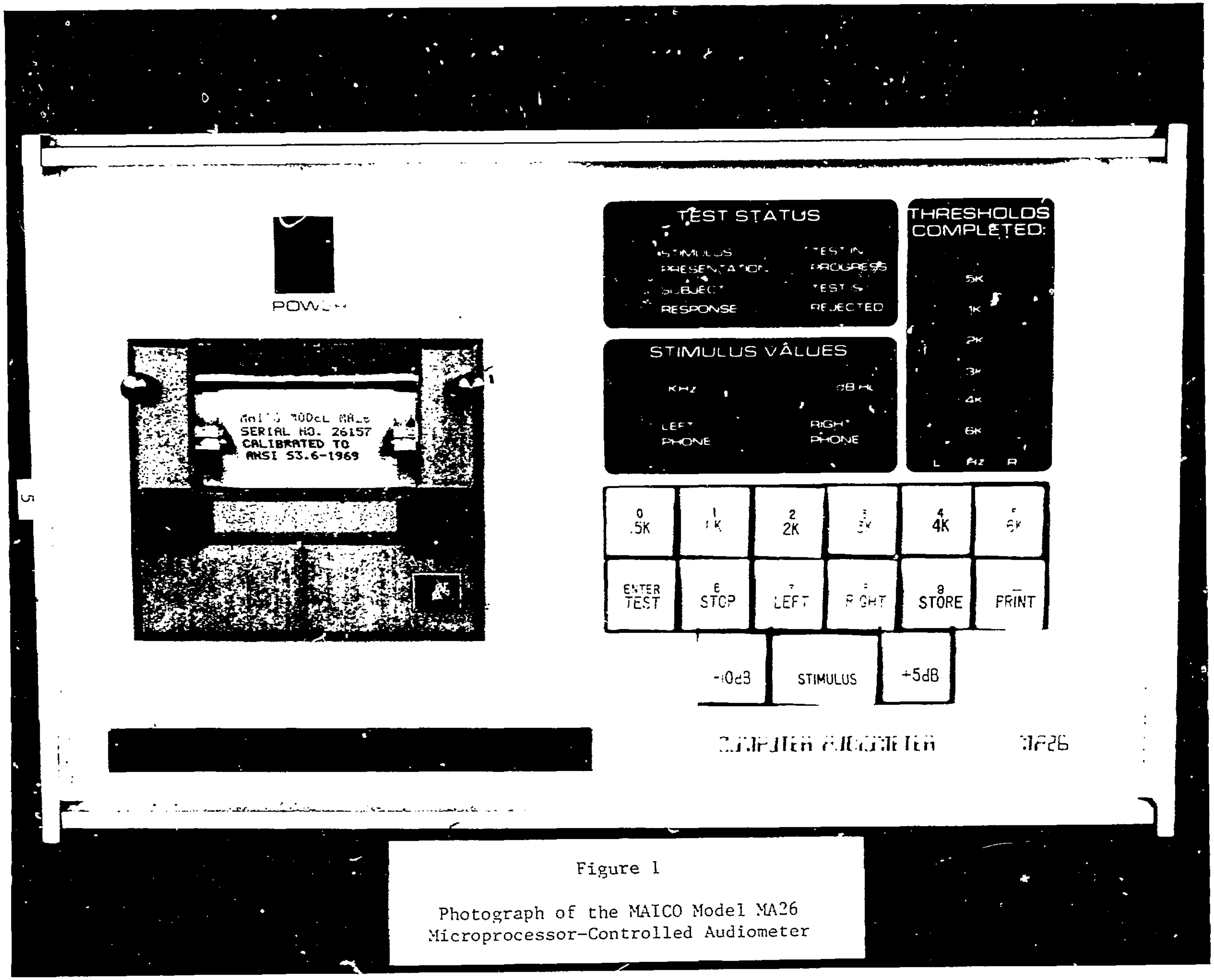

Figure 1

Photograph of the MAICO Model MA26
Microprocessor-Controlled Audiometer

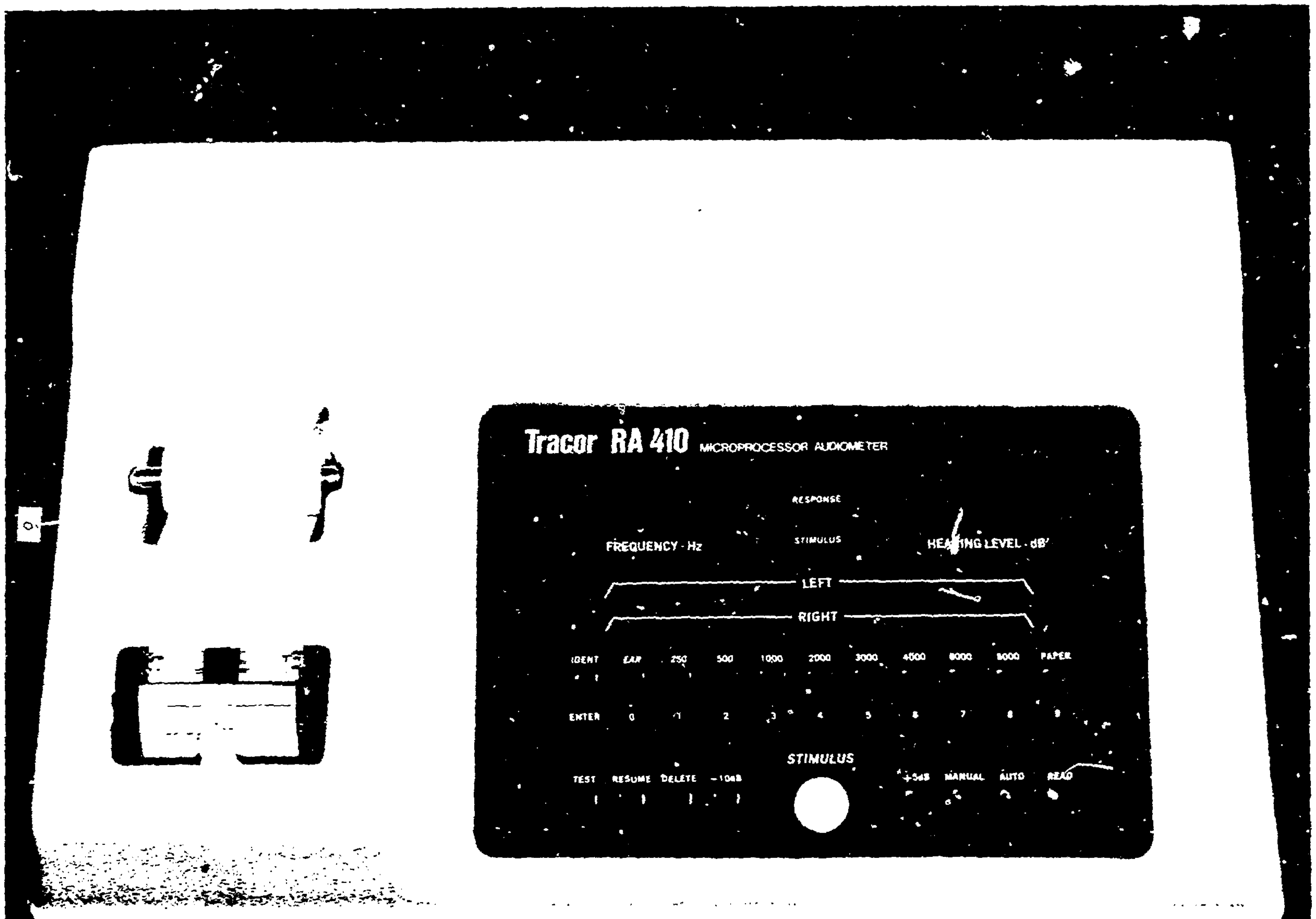

Figure 2

Photograph of the TRACOR Model RA 410
Microprocessor-Controlled Audiometer

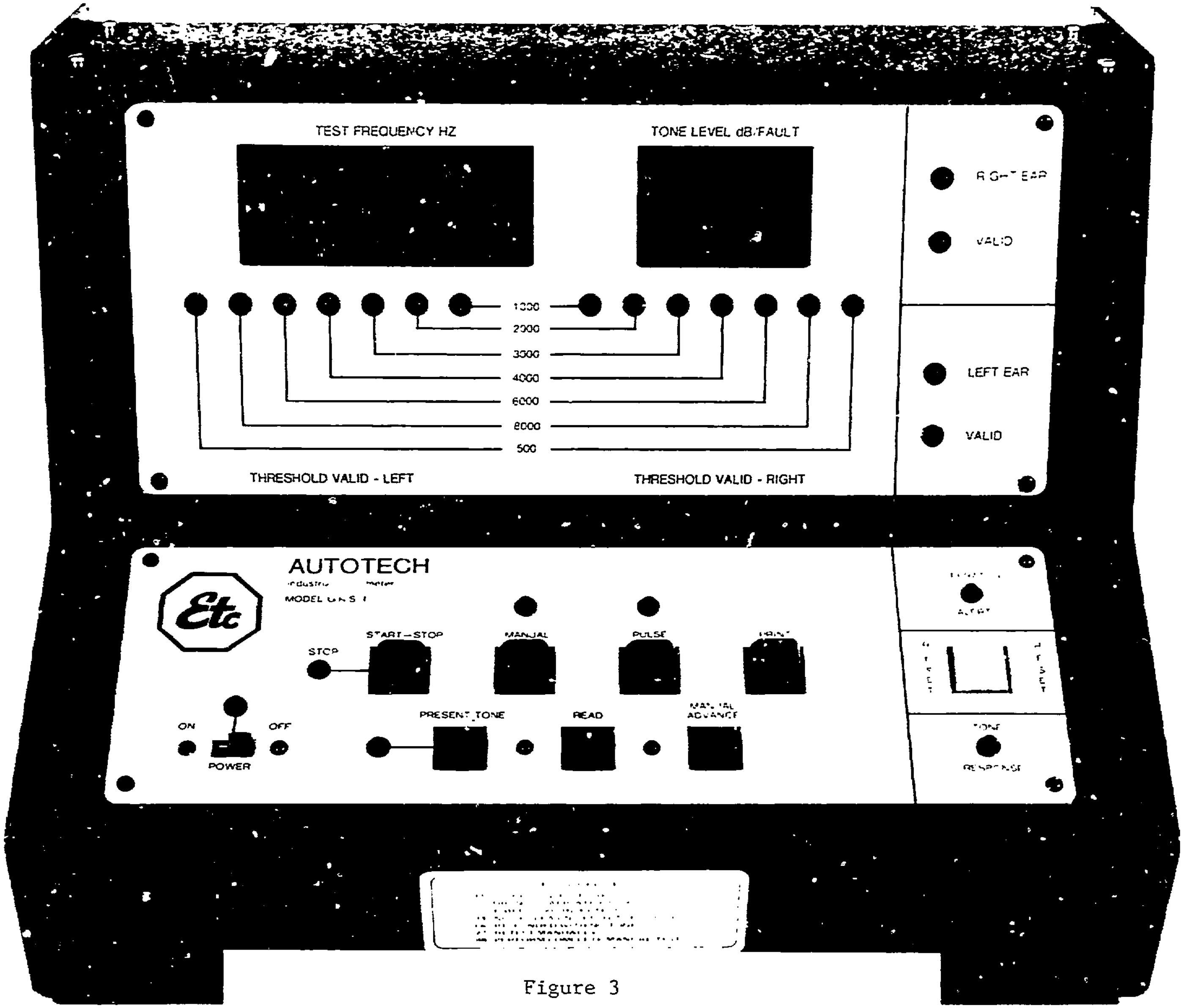

Figure 3

Photograph of the Environmental Technology Corporation
Model G.R.S.-1 Microprocessor-Controlled Audiometer

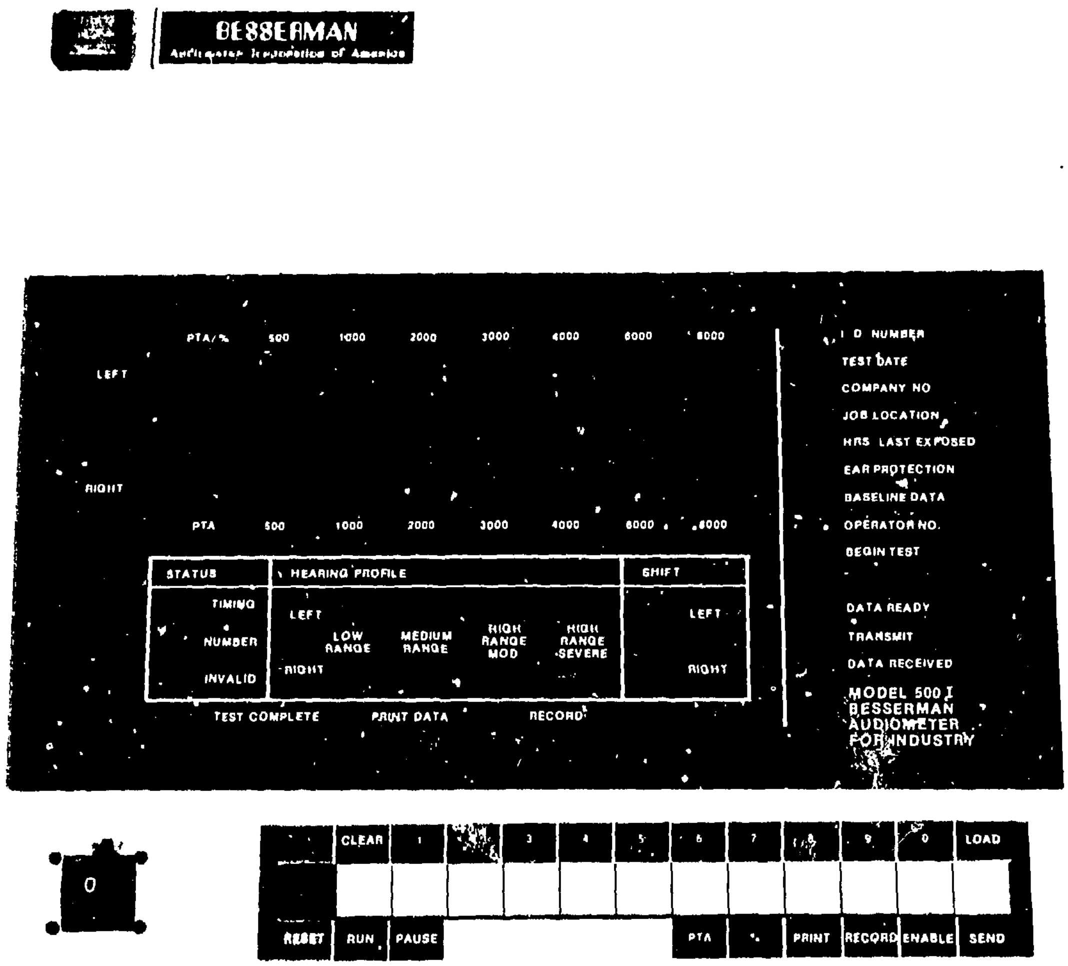

Figure 4

Photograph of the Audiometer Corporation of America
Model 500 I Microprocessor-Controlled Audiometer

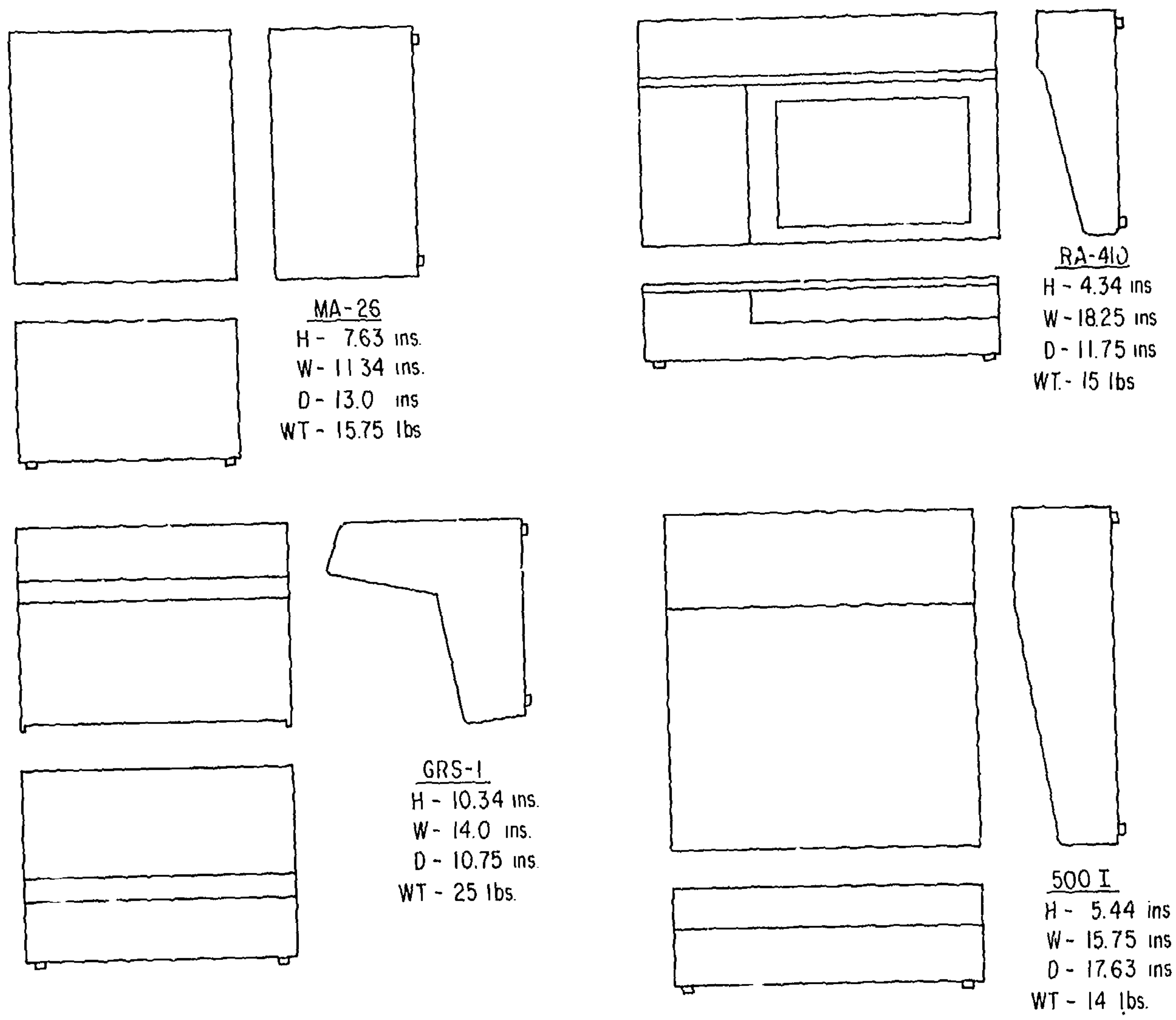

Figure 5

Dimensions and weight of the four microprocessor-controlled audiometers evaluated.

- A description of the test logic patterns employed by the four devices.

RATING OF FEATURES

Two electronics specialists, the audiometric technician who conducted the hearing tests, and a research audiologist individually assigned ratings to various features of the instruments. A five-point rating scale with "one" defined as "poor" and "five" as "outstanding" was utilized; the adjectives "fair," "average," and "good" were assigned to the intermediate values. The features were rated relative to their anticipated utility or desirability for application in Navy hearing conservation programs. Eighteen features relating specifically to maintenance, repair, and calibration aspects of the equipment were rated.* In addition, forty-four general features of the audiometers, covering such areas as stimulus characteristics, input-output information, computational capability, data storage capacity, and subject-related features were rated separately.**

For each of the two feature categories and for each device, a total was calculated of the ratings assigned by each rater. For the maintenance, repair, and calibration category, which had approximately 2½ times fewer features than the general category, a weighted total was assigned. The ratings for the two categories were then averaged, resulting in an overall rating for each device.

COMPARISON OF MANUAL AND AUTOMATED SYSTEMS

The HTLs of 250 subjects*** were determined for the purpose of comparing HTL measures and test time required for the automated and manual testing techniques. One hundred twenty-five of the subjects had normal hearing and the others were classed as having high frequency sensorineural hearing losses.

Subject selection criteria for both the normal hearing and sensorineural hearing loss groups were as follows:

- no greater than 40 dB HTL separation between ears at any frequency

- no ascending low frequency configurations; i.e., 15 dB or greater difference between HTLs at 500 Hz and/or 1 or 2 kHz.

Normal hearing was defined as no HTL greater than 20 dB at 500, 1000, and 2000 Hz and no greater than an average of 25 dB for the frequencies 3000, 4000, and 6000 Hz, either ear. Sensorineural hearing loss was defined as an average of 30 dB or greater for the frequencies 3000, 4000, and 6000 Hz, either ear.

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*See Table A I
**See Table B I
***From the Marine Air Training Support Group, Naval Air Rework Facility, and the Public Works Center, NAS Pensacola.

For each device, HTLs were obtained from each ear of 25 normal-hearing individuals and 25 individuals with sensorineural hearing losses.* Hearing threshold levels were also obtained on the same subjects utilizing manual audiometry (Maico, Model MA24).

The manual test tone sequence was always 1, 2, 4, 8, 6, 3, and 0.5 kHz with the right or better ear always tested first. The technician started the threshold search at 30 dB and, if no response was obtained, the signal level was increased in 15-dB steps until the subject responded. When a response was obtained, the level was decreased by 10 dB until a "no response" point was reached. Following a "no response," the level was increased 5 dB until a response was elicited from the subject. The 10 dB down/5 dB up sequence continued until two out of three responses were obtained at the same level. This level was defined as the HTL.

Prior to the evaluation of each of the four automated instruments, physical calibration checks were conducted with Bruel and Kjaer measurement equipment.** The manual and automated devices were also physically checked throughout the period of data collection. If calibrations were found to be incorrect for those devices with trimpots (MA26, RA 210), they were re-calibrated to the exact levels specified by ANSI S3.6-1969 (12). If those devices with firmware calibration systems, i.e., erasable programable read only memories (EPROMs), (ACA 500 I and ETC G.R.S.-1), were found to be out of calibration, appropriate numeric corrections were applied to the HTL data. (The equipment necessary for erasing and reprogramming the EPROMs was not requested from the manufacturer.)

The time required to determine HTLs for each of the subjects on the various instruments was measured with an electric timer.*** These measurements did not include the time taken by the technician for instructions to subjects, filling out forms, or entering identifying information into some of the automated units.

DESCRIPTION OF TEST LOGIC PATTERNS

The hearing threshold logic patterns were studied for each of the four devices. These logic patterns are responsible for the nature of signal level adjustments following a "response" or "no response" from the subject. The time taken for convergence to a hypothetical threshold was also determined for each of the instruments.

FIELD EVALUATION

In addition to the laboratory assessments, field evaluations were

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*Two different groups of subjects were tested on the G.R.S.-1 system for both the normal-hearing and sensorineural hearing loss categories; i.e., 25 "normals" and 25 "sensorineurals" on the automated single-tone mode, and 25 "normals" and 25 "sensorineurals" on the automated pulsed mode.
**Sound level meter (Type 2203), microphone (Type 4144), octave filter set (Type 1613), earphone coupler (Type 4151), and pistonphone (Type 4220).
***Standard Electric Time Company, Type S-10.

conducted on a G.R.S.-1 group unit at the Baltimore AFEES (N=80) and on a G.R.S.-1 individual unit at the Branch Clinic, NAS Pensacola (N=200). Data gathered in both instances related to the type and percentage of fault codes (errors) generated by the subjects. In addition, general information about the operation of the equipment in a field situation was obtained.

Laboratory and field assessments extended over a period of approximately nine months. Based upon the information generated during this period, tentative performance specifications were written for a non-group microprocessor-controlled audiometer that would meet Navy hearing conservation program requirements.

RESULTS AND DISCUSSION

RATING OF FEATURES

Figure 6 shows the average rating totals and overall ranking of the four MCAs. Individual judge's ratings for each of the 44 general features and the 18 maintenance, repair, and calibration features are shown in Appendices A and B. As was stated previously, all features of the instruments were rated relative to their anticipated utility or desirability for application in Navy hearing conservation programs. Other potential users with different requirements would undoubtedly generate a different ranking. In most instances, the ranking does not necessarily reflect the quality or lack of quality of the MCAs. It should also be pointed out that the instruments evaluated and described herein may not represent the manufacturer's most recent model. They were, of course, the most recent models at the time of the evaluations.

As can be seen, the Tracor and ETC instruments are indistinguishable on the basis of ratings for the general features category. The Maico and Tracor systems are very similar, when maintenance, repair, and calibration features are compared. The overall ratings show the Maico unit ranked first, the Tracor second, and the ETC instrument next. The ACA system was ranked last in both major categories.

TEST LOGIC PATTERNS

The logic pattern utilized by each of the instruments is shown in Table I. All of the units employ a variation of the modified Hughson-Westlake procedure (10), although it should be noted that, because the logic patterns are under firmware* control, changes in these test paradigms are easily effected. Some comment on the logic patterns employed in the devices evaluated is given below.

In the Maico unit, after the first threshold determination, subsequent frequencies are presented at a level 10 dB above the threshold at the previous frequency. This feature works well for a sloping sensorineural hearing

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*Programs stored in PROMs or EPROMs as opposed to magnetic tapes or disks.

Table I

Test Paradigms

Unit	Initial Presentation Level	If Response Obtained:	If No Response Obtained:
MAICO MA26	40 dB (After first threshold determination, subsequent frequencies are presented 10 dB above the threshold obtained at the previous frequency.)	-drops 10 dB until no response, then -up in 5 dB steps until response, then -drops in 10 dB steps etc., variations at 5 & 0 dB -two responses are required at the same level for threshold, the initial response is not counted	up 20 dB
TRACOR RA 410	40 dB	-drops 20 dB until no response, then -up in 5 dB steps until response, then -drops in 10 dB steps, etc., variations at -5 and -10 dB -three responses, which can be non-consecutive, are required at the level for threshold	up 10 dB
ETC G.R.S.-1	30 dB	-drops 10 dB until no response, then -up in 5 dB steps until response, then -drops in 10 dB steps, etc., variations at 5 & 0 dB -three responses, which can be non-consecutive are required at the same level for threshold	up 30 dB
ACA 500 I	30 dB	-drops 10 dB until no response, then -up in 5 dB steps until response, then if response is preceded by three ascending no responses, threshold will be at the level where <u>single</u> response is obtained -otherwise drops in 10 dB steps until no response etc., variations at 5 and 0 dB -two responses are required at the same level for threshold with the above exception	up 15 dB

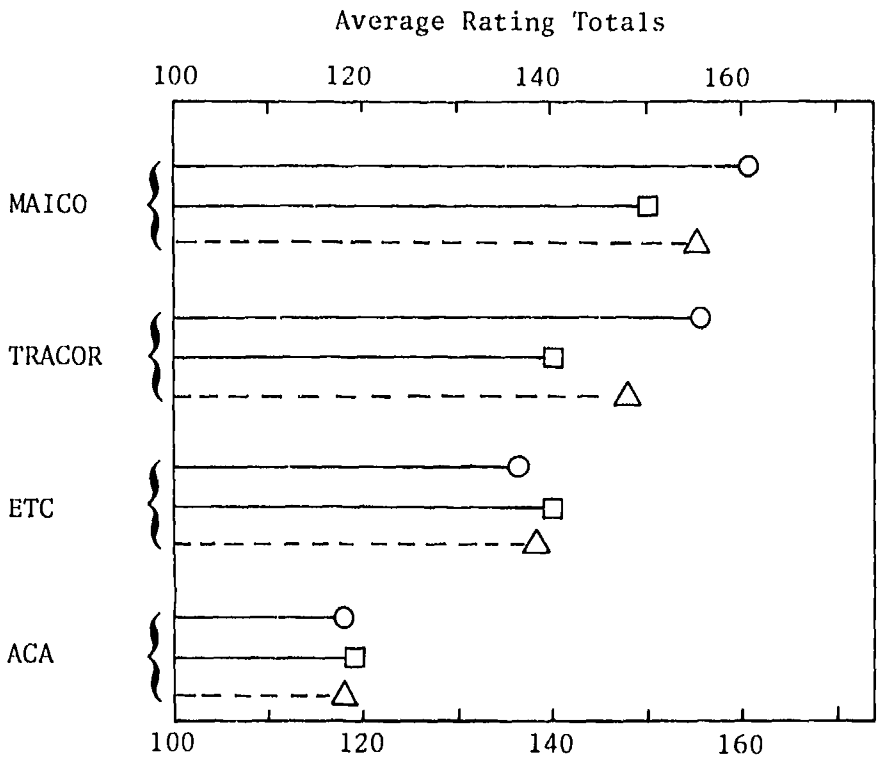

Figure 6

Average rating totals for maintenance, repair, and calibration features (O), general features (□), and overall ratings (△) for the four microprocessor-controlled audiometers.

loss. It would not be suitable for ascending HTL configurations where the tone would be unnecessarily loud for the high frequencies. It was noted that under certain conditions, the ACA instrument assigns a threshold value based on a single response.

The test frequency sequence and threshold validation features for each of the units are shown in Table II. These features are also under firmware control and modifications can be easily made. The Maico unit rejects the test and sounds an audible signal if the third 1-kHz presentation is not within ± 5 dB of the best of the two previous thresholds. The provision of two comparisons at 1 kHz and two determinations at 0.5 kHz is not felt to be necessary. The Tracor technique is acceptable except that both ears should be subjected to the 1-kHz validation. In the event that validation does not occur, the examination stops and a partial print-out is done. The ETC threshold validation occurs too late in the test sequence (after all other frequencies for an ear have been tested). Thus, if a subject fails the 1-kHz retest, nearly all of the test frequencies for that ear would have to be repeated. In the ETC unit, an audible tone is generated and a visual error warning is displayed by LEDs if the 1-kHz retest is failed. Although the ACA unit did not have a validation program, a 1-kHz practice period was provided. Only the second 1-kHz measurement was stored as threshold.*

Table II

Description of Test Frequency Sequence and Threshold Validation Criteria for the Four Microprocessor-controlled Audiometers (MCAs)

MCA	Test Sequence Frequency (kHz)	Validation Frequency	Ear(s)	Criteria
MAICO	1,0.5,1,0.5,1,2,3,4,6	1k	Left only	± 5 dB better of 2 previous
TRACOR	1,0.5,1,2,3,4,6,8	1k	Left only	± 5 dB
ETC	1,2,3,4,6,8,1,0.5	1k	Both ears	± 5 dB
ACA	1,0.5,1,2,3,4,6,8	None (1 kHz is used for practice)		

The logic patterns employed by each of the four MCAs for establishing a hypothetical threshold of 35 dB are shown in Figure 7. As can be seen, three of the units arrive at threshold in approximately 22 seconds, while the Tracor system requires about five seconds longer. Note the considerable variability among the instruments during the first half of the overall time period. The ETC unit provides twice as many stimulus events as does the

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*The current ACA unit does have a 1-kHz validating feature.

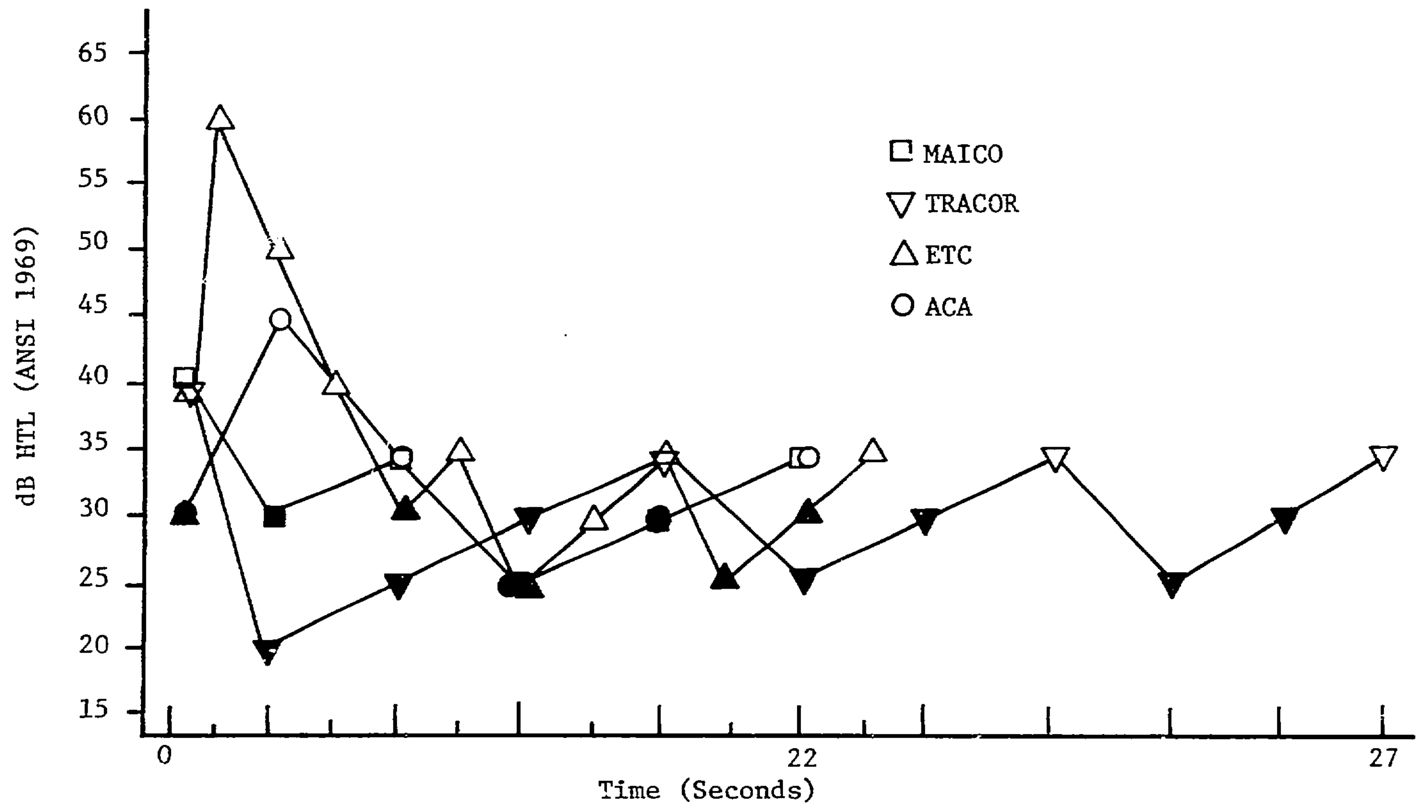

Figure 7

Logic patterns employed by each of the four microprocessor-controlled audiometers in establishing a hearing threshold level of 35 dB. Filled symbols represent "no responses" and open symbols represent "responses."

Maico or ACA instrument during the same time period. A combination of the stimulus presentation speed of the ETC unit together with the threshold criteria of the Maico unit would produce a very efficient test paradigm.

Variations of the threshold criteria occur in each of the audiometers at or near their lowest signal levels. Figure 8 presents a diagramatic representation of these variations. Note the unique "pause" feature in the logic of the ETC unit at the 0 dB HTL.

COMPARISON OF AUTOMATED VS MANUAL TESTING TIMES AND HTLS

Table III shows the average time required to test six frequencies (500-6000 Hz) for each of the four MCAs, compared with the time required to perform testing on a Maico Model MA24 manual audiometer. More detailed information concerning the time measurements may be seen in Appendix E. For the normal-hearing group, average test durations for the MCAs were nearly equal to, or shorter than, test durations for manual testing. With one exception, the same held true for the sensorineural group. The Maico instrument took an average of one minute longer than required for manual testing. This one-minute time difference between automated and manual testing would result in an 8-subject difference per work day, if one assumed seven hours of continuous testing. The subject difference would increase to about 24 per day if one considers the fastest (ETC) and the slowest (Maico) automated instrument for individuals having sensorineural hearing loss, for example. There is a trend toward longer test times for the sensorineurals and it appears to be slightly more pronounced for the MCAs.

Table III

Average Test Duration (Minutes) for Automated and Manual Testing (6 frequencies)* on Normal Hearing (N) and Sensorineural (S) Subjects

Audiometer	Subject	Automated	Manual	Difference
MAICO	N	6.2	6.1	+0.1
	S	8.0	6.9	+1.1
TRACOR	N	6.8	6.6	+0.2
	S	7.0	6.9	+0.1
ETC	N	5.0	6.1	-1.1
	S	5.5	6.7	-1.2
ACA	N	5.0	5.6	-0.6
	S	6.0	6.4	-0.4

*0.5,1,2,3,4,6 kHz

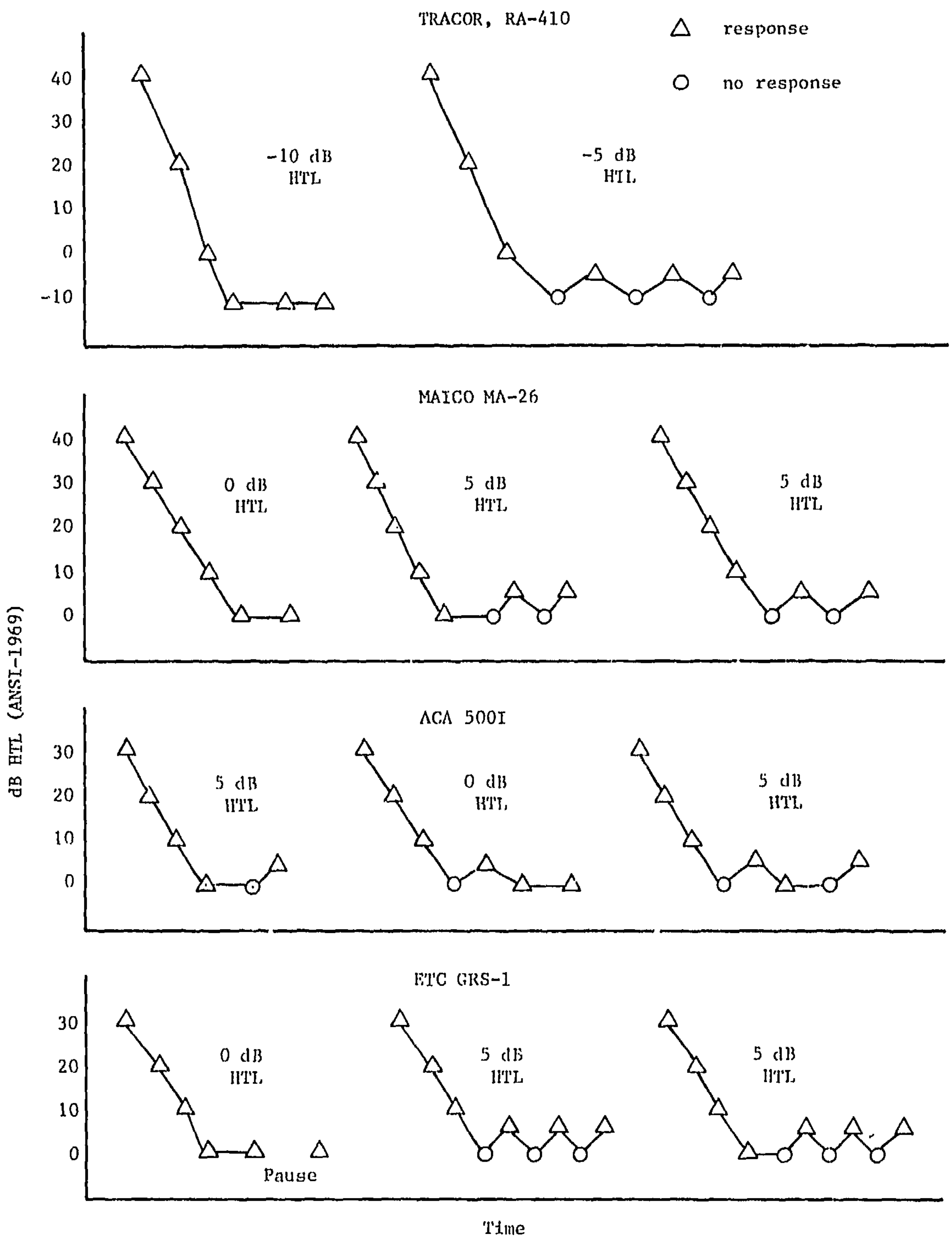

Figure 8

Threshold logic pattern variations at or near the lowest signal levels produced by each of the four audiometers.

While differences in testing times of these magnitudes may be critical in some specific circumstances, they are not sufficiently disparate to make testing time a high priority factor for the selection of one unit over another, or for rejecting the utility of the MCAs. The obviation of the interpretation of the self-recording audiometer card (as is currently necessary) would be sufficient to make up for any slight time disparities.

The differences in HTLs derived from manual and automated audiometry for each of the four MCAs are shown in Figure 9. Each data point represents the average HTL determined from 50 ears. A total of 200 subjects was examined. Decibel differences above the "0" line indicate that the HTL derived from automated testing was lower (reflecting better hearing) than the HTL derived from manual audiometry. Decibel differences below the line indicate that the HTL derived from automated testing was higher (poorer hearing) than the HTL obtained from manual audiometry. Note the lack of any appreciable differences between the normal-hearing and sensorineural subject groups in regard to automated vs manual HTLs. The maximum threshold difference for any instrument at any frequency was about 4 dB. This finding was somewhat unexpected for the Tracor and ETC instruments (which employ a single 1.2-second tone*, as opposed to the pulse tone sequence employed in the other instruments) since one would expect that for the continuous tone condition, the sensorineural subjects, some of whom had tinnitus, would perform differently from the normal-hearing subjects. In general, it is clear from these data that the MCAs produced, within acceptable variation, HTLs comparable to those obtained with manual audiometry.

FAULT CODES

The "fault code" concept of providing immediate visual and/or auditory signals to the audiometric technician, indicating that the test is not progressing normally, is felt to be an excellent one. Of the instruments evaluated, the ETC device, which employs 7 fault codes, makes the most extensive use of this warning system and was chosen for the following fault code analysis. As was mentioned previously, 200 subjects were tested at the NARMC Branch Clinic, NAS Pensacola, and tests of another 80 subjects were observed at the Baltimore AFEES (8-man group test environment). The percentages of total faults made by the subjects for the different codes were calculated and are presented in Figure 10. The total number of errors for the AFEES group testing was 39, automated single tone (Pensacola) - 67, and automated pulse tone (Pensacola) - 54. Overall average error rates per subjects tested were 0.49, 0.67, and 0.54, respectively. Note that the lowest overall error rate was observed in the group test situation.

The greatest proportion of the errors occurred for two fault codes. The most frequent error was "responding when no tone was present" (Fault Code 66) and the other was "failure of the 1000-Hz retest" (Fault Code 33). The use of a pulse tone stimulus appears to reduce the frequency of Code 66 errors. It is felt that fault warnings should be immediate, unambiguous, and highly apparent to the technician.

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*Either single tone or pulse tone sequence can be selected in the ETC unit.

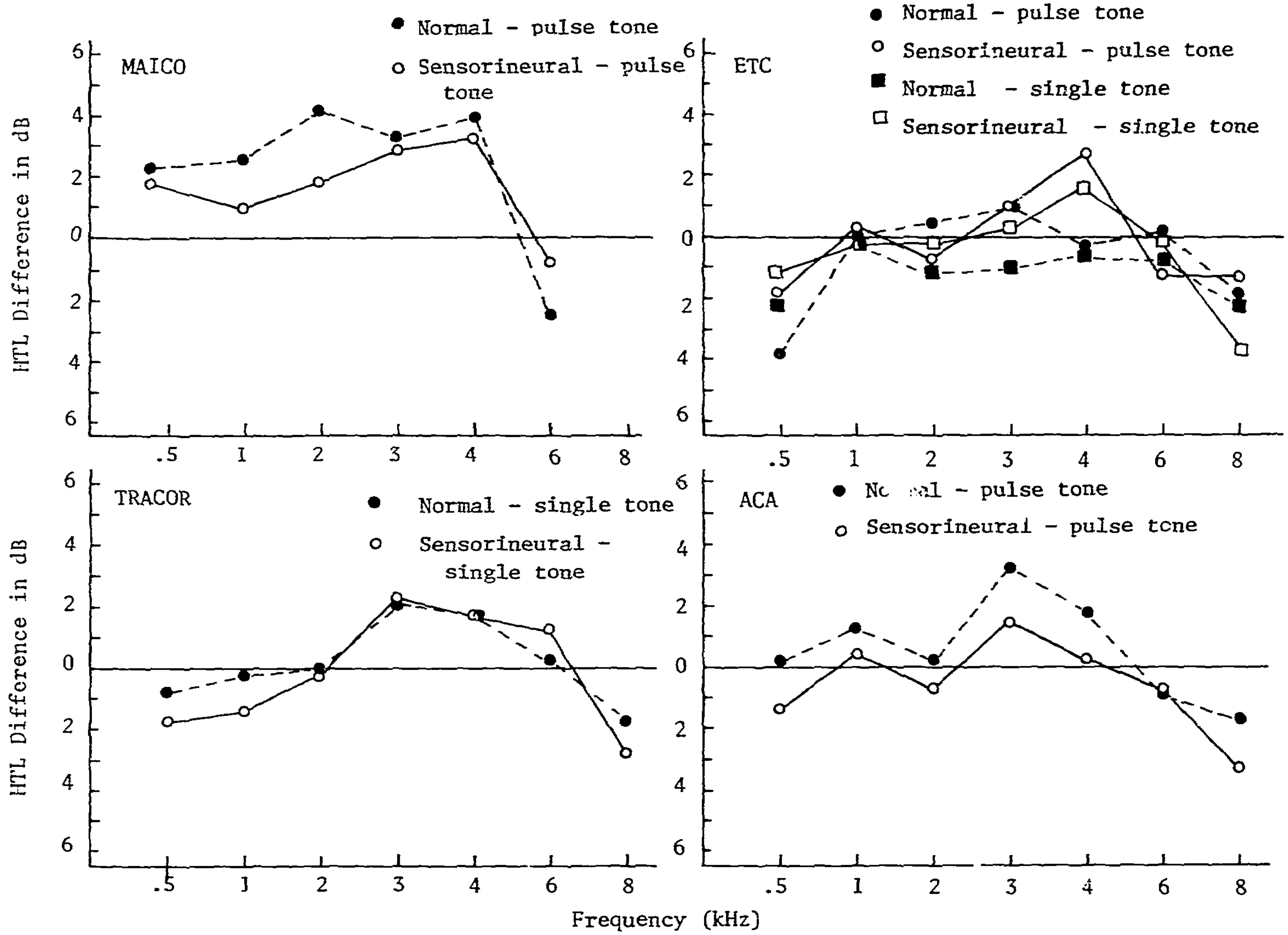

Figure 9

Difference in hearing threshold levels (HTLs) obtained from manual and automated audiometry for each of four different *microprocessor*-controlled audiometers (MCAs). Data points below the zero line indicate that thresholds obtained with the MCAs were poorer than thresholds obtained with manual audiometers. Right and left ear HTL data combined (50 measurements per data point).

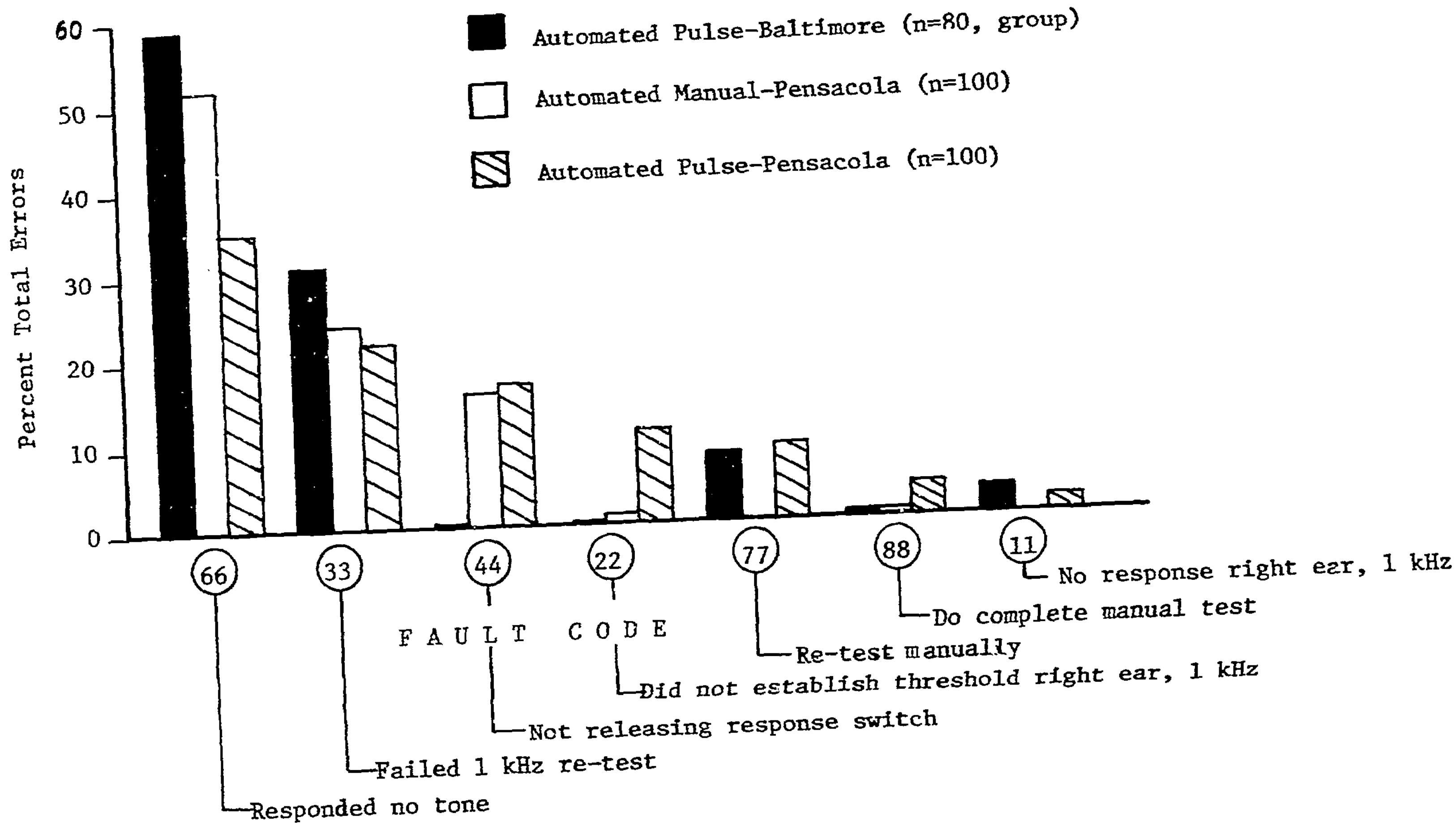

Figure 10

Percentage of total errors for each of seven ETC fault codes
for three different test conditions

TENTATIVE PERFORMANCE SPECIFICATIONS

By utilizing the knowledge gained during the assessment of the four MCAs, as well as information gained from a number of laboratory and field sources concerning currently known requirements for hearing conservation programs, a listing was made of tentative performance specifications for a "non-group"* MCA for Navy use. The listing is presented in Table IV. The specifications relating to threshold criteria and the stimulus related parameters will perhaps be modified at a later date. An investigation of some of these factors is currently being conducted at the Naval Submarine Medical Research Laboratory (NSMRL), New London. Recommendations based on the results of the NSMRL study will be considered in any revision of the specifications list.

Some of the specifications listed in Table IV require clarification and further explanation. The inclusion of 8000 Hz is considered necessary since the microprocessor units will also be utilized for other than hearing conservation purposes. Certain Navy job specialties require the testing of this frequency during service entry or as part of retention physical examinations. The dB range includes minus 10 because HTL shift is used as an index of susceptibility to noise and, for maximum protection of the individual, baseline thresholds must be measured so that the lowest HTLs can be recorded. It is felt that a single test paradigm, or logic pattern, should be contained within the microcomputer. The provision for multiple test logics, either when selectable by the technician or automatically selected, is not considered desirable. Such a feature would defeat one of the primary reasons for the development of a Navy MCA--that of homogeneity of audiometric testing techniques, Navy-wide.

If one could combine certain features from each of the units evaluated, and add some additional features, the tentative specifications listed in Table IV could be met. For example, by combining the integral, modular impact printer of the Maico, the error warning of the ETC, the dB range of the Tracor, the data management programming of the ACA, and an on-board magnetic storage device, one would have an instrument close to what is felt necessary for use in Navy hearing conservation programs.

CONCLUSIONS

Microprocessor-controlled audiometers produce, within acceptable variation, hearing threshold levels comparable to those obtained with manual audiometry and within similar time frames. The new generation of audiometers makes it possible for any threshold seeking procedure to be programmed and standardized at all test locations. Moreover, these automated hearing test instruments can also be programmed to provide fault detection algorithms which make it difficult for individuals to falsify the audiometric data. Tentative performance specifications have been identified for the development of an MCA for use in Navy hearing conservation programs. Since none of the instruments evaluated incorporates all of the tentative specifications, it would be premature for the Navy to purchase any off-the-shelf MCAs for use in its hearing conservation programs.

*A field assessment of a "group" MCA will be undertaken prior to establishing specifications for "group" testing configurations.

Table IV

Tentative Performance Specifications for a Non-group Microprocessor-Controlled Audiometer for Use in Navy Hearing Conservation Programs

STIMULUS SPECIFICATIONS

- Test frequencies 500-8000 Hz
- Decibel range minus 10 to 90 dB
- * Variable interstimulus interval
- * Three pulse stimulus presentation
- Single test paradigm
- * Threshold criterion: two responses at same level after initial response, 40 dB start; if no response at start point, increase level by 20 dB, modified Hughson-Westlake procedure
- Repeat 1000 Hz both ears with ± 5 dB agreement necessary
- Ear sequence R/L fixed in automatic mode; selectable in calibrate mode
- Meet all current ANSI specifications for audiometers

INPUT/OUTPUT/STORAGE SPECIFICATIONS

- Integral, modular, impact, solid ink printer
- Several immediate error warnings with auditory and visual signals to the technician:
  - Failed 1 kHz recheck (± 5 dB agreement required, either ear)
  - Can't establish threshold on 1 kHz pre-test (either ear)
  - Responded with no tone presented
  - No response or 50 dB or greater threshold on 1 kHz pre-test (either ear)
  - * Holding response switch too long (> 5 sec)
- Minimal use of multifunction keys
- Automatic printing of serial number and calibration date
- Test date is printed after initial entry until power is terminated
- Mini numeric keyboard
- * Identifying information and reference audiogram for subject and ID information for test site input by magnetic card
- * RS-232, GPIB
- * LED or LCD display (alpha-numeric)
- * Integral, modular cassette, cartridge or micro-disk storage unit
- Time of day on printout

COMPUTATIONAL SPECIFICATIONS

- Compute threshold shift and, if significant, warn technician
- * Classify hearing loss
- Calculate hearing threshold level averages (.5,1,2 kHz & 3,4,6 kHz each ear)

- - - - - - - - - - -

*Not fully defined at present

TABLE IV (Continued)

MAINTENANCE, REPAIR AND CALIBRATION SPECIFICATIONS

- Individual headphone calibration
- Excellent S/N ratio at high signal levels
- Separate plug-in printed circuit boards for major functions
- Calibrate mode: by switch inside unit with automatic setting of attenuator to 70 dB continuous tone and 500 Hz with subsequent manual frequency and earphone selection
- Easy access fuses or circuit breakers
- Plug-in ICs
- Cords and plugs compatible with existing test booths
- Good component accessibility
- State of the art microprocessor and memory devices
- Freedom from thermally-related problems with 40-60W power consumption-no fan
- Good anchoring of components for shipping
- Integral, modular, impact solid ink printer
- EMI line filter
- Firmware (EPROM) calibration with self burning capability, i.e., EPROM need not be removed from instrument

SUBJECT RELATED SPECIFICATIONS

- Talk-over
- Test duration approximately 8 minutes or less
- Test pause capability
* Limit for threshold determination - 20 presentations
- Automatic retest of missed frequencies

- - - - - - - - - -

*Not fully defined at present

RECOMMENDATIONS

It is recommended that a field evaluation of a group MCA be undertaken to supplement data obtained on the four MCAs described herein. Subsequently it should be possible to finalize instrument specifications for Navy use and to submit the specifications as a statement of work to various manufacturers. The manufacturer best able to meet the Navy specifications should be asked to construct several pre-production models for test and evaluation during FY-80.

It is further recommended that FY-81 be considered as the target time frame for initiating the utilization of group automated hearing testing into Navy hearing conservation programs.

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Appendix A

Maintenance, Repair, and Calibration Features

of MCAs Tested

Table A I

Maintenance, Repair, and Calibration Features
and Their Assigned Code Numbers*

Code Number	Feature
1	Circuit boards
2	Separate boards for major functions
3	Circuit board replacement affects calibration
4	Headphone calibration
5	Calibration
6	Calibrate tone on
7	Calibrate-attenuator stepping method
8	Calibrate-frequency stepping method
9	Calibrate-auxiliary programmer required
10	Printer
11	Fuses or circuit breakers
12	ICs
13	Major components anchored for shipping
14	Cords and plugs compatible with booths
15	General component accessibility good
16	Microprocessor
17	Memory type
18	Thermal problems

*Feature code numbers are used in subsequent tables of this Appendix

Table A II

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the Maintenance, Repair, and Calibration Features of the MAICO MA26

Sum of Ratings	Feature Code	Description	A	B	C	D
15	1	Plug-ins (1 main, 3 other)	4	3	5	3
17	2	Yes	5	4	4	4
12	3	Yes, if audio board	3	2	4	3
18	4	Individual	4	5	4	5
17	5	Trimpots, remove top	4	4	5	4
7	6	Jumper to ground**	2	2	1	2
13	7	Manual	4	3	3	3
13	8	Manual	4	3	3	3
15	9	No	4	4	4	3
17	10	Integral, modular, impact	5	4	4	4
10	11	Internal fuse	3	2	2	3
16	12	Plug-in	4	4	5	3
15	13	Yes	4	4	4	3
17	14	Yes	4	5	5	3
16	15	Yes	4	4	4	4
15	16	8080	4	4	4	3
15	17	2708 PROM (3)	4	4	4	3
16	18	No	4	4	5	3
			70	65	70	59
				= 264		
				$\bar{x}$ = 66		
		Weighted (66)(2.44)		= 161		
				$\bar{x}$ = 3.67		

*1=poor, 2=fair, 3=average, 4=good, 5=outstanding

**Subsequently changed to a more acceptable technique

Table A III

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the Maintenance, Repair, and Calibration Features of the TRACOR RA 410

Sum of Ratings	Feature Code	Description	A	B	C	D
16	1	3 Plug-in	4	3	5	4
17	2	Yes	5	4	4	4
12	3	Yes, if audio board	3	2	4	3
18	4	Individual	4	5	4	5
17	5	Trimpots, bottom access	4	4	5	4
12	6	Hold down stim. switch man. mode	3	3	4	2
13	7	Manual	4	3	3	3
13	8	Manual	4	3	3	3
15	9	No	4	4	4	3
15	10	Integral, non-modular, thermal	4	4	4	3
16	11	External, easy access	4	4	5	3
16	12	Plug-in	4	4	5	3
15	13	Yes	4	4	4	3
17	14	Yes	4	5	5	3
7	15	No	2	2	1	2
15	16	8080	4	4	4	3
15	17	2708 PROM	4	4	4	3
7	18	Yes	2	2	2	1
			67	64	70	55
				= 256		
				$\bar{x}$ = 64		
		Weighted (64)(2.44)		= 156		
				$\bar{x}$ = 3.56		

*1=poor, 2=fair, 3=average, 4=good, 5=outstanding

Table A IV

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the Maintenance, Repair, and Calibration Features of the ETC G.R.S.-1

Sum of Ratings	Feature Code	Description	A	B	C	D
14	1	10 Plug-ins	4	2	4	4
17	2	Yes	5	4	4	4
12	3	Yes, if audio board	3	2	4	3
9	4	Matched set	3	1	3	2
8	5	EPROM	2	3	1	2
13	6	Hold down stim. switch man.mode	4	3	4	2
13	7	Manual	4	3	3	3
13	8	Manual	4	3	3	3
5	9	Yes	2	1	1	1
10	10	Peripheral, thermal	3	2	3	2
16	11	External, easy access	4	4	5	3
7	12	All but 2 soldered	3	1	1	2
15	13	Yes	4	4	4	3
17	14	Yes	4	5	5	3
8	15	No	2	2	2	2
15	16	8080	4	4	4	3
15	17	2708 PROM	4	4	4	3
16	18	No	4	4	5	3
			63	52	60	48
				= 223		
				$\bar{x}$ = 56		
		Weighted (56)(2.44)		= 137		
				$\bar{x}$ = 3.10		

*1=poor, 2=fair, 3=average, 4=good, 5=outstanding

Table A V

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the Maintenance, Repair, and Calibration Features of the ACA 500 I

Sum of Ratings	Feature Code	Description	A	B	C	D
5	1	Two hand wired bread boards	2	1	1	1
6	2	No	2	1	2	1
8	3	Yes	3	1	1	3
18	4	Individual	4	5	4	5
8	5	EPROM	2	3	1	2
7	6	Reverse dip socket	1	2	2	2
13	7	Manual	4	3	3	3
13	8	Manual	4	3	3	3
4	9	Yes	1	1	1	1
8	10	Peripheral, impact (MP-40)	1	3	2	2
11	11	One external easy access, three internal	3	3	2	3
15	12	Plug-in	4	4	4	3
15	13	Yes	4	4	4	3
17	14	Yes	4	5	5	3
15	15	Yes	4	4	4	4
7	16	SC/MP	1	2	2	2
7	17	MM5204 PROM	1	2	2	2
16	18	None	4	4	5	3
			49	51	48	46
				= 194		
				X = 48.5		
		Weighted (48.5)(2.44)		= 118		
				$\bar{x}$ = 2.69		

*1=poor, 2=fair, 3=average, 4=good, 5=outstanding

Appendix B

General Features of MCAs Tested

Table B I

General Features and Their Assigned Code Numbers

Code Number	Feature	Code Number	Feature
1	Test frequencies	23	Intercom
2	Delete frequency capability	24	Type of display
3	Ear sequence	25	Test pause capability
4	Repeat frequencies	26	Number of error warnings
5	Decibel range	27	When errors warnings
6	Number of signal pulses	28	Auditory signal to technician
7	Number of test paradigms	29	Visual signal to technician
8	Type of test paradigm	30	Audiogram storage capacity
9	Variable inter-stimulus interval	31	Classifies loss
10	Variable stimulus duration	32	Pure tone average computation
11	Threshold criterion	33	AAOO computation
12	Test time per subject	34	Significant threshold shift comp.
13	ID information entry	35	Power consumption
14	ID information capacity	36	CRT terminal
15	Hard copy unit	37	Max. time per frequency
16	Type of printer	38	Re-test of missei frequencies
17	Integral printer	39	Re-test mode
18	Calibration	40	Automatic print of serial number
19	Automatic slowing of test	41	Manual test capability
20	RS-232	42	Prints out all subject responses
21	GPIB	43	Multi-function keys
22	TTY	44	Signal-to-noise ratio

Table B II

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the General Features of the MAICO MA26

Sum of Ratings	Feature Code	Description	A	B	C	D
14	1	500 to 6000 Hz	4	3	3	4
10	2	No	3	3	1	3
11	3	R/L	3	2	3	3
12	4	1000 Hz right ear	3	3	3	3
13	5	0 to 95 dB	3	3	4	3
13	6	Three pulse train	3	3	4	3
14	7	One	3	4	4	3
14	8	Manual	3	4	4	3
14	9	Yes, 2 to 4 sec.	4	4	2	4
11	10	Fixed, 100 msec.	3	3	2	3
17	11	2 same level after initial	4	5	4	4
10	12	7 to 10 min.	3	1	3	3
12	13	Keyboard (numeric)	3	3	3	3
13	14	25	3	3	3	4
12	15	Printer	3	3	3	3
16	16	Impact solid ink supply	4	5	4	3
17	17	Yes, modular	5	3	5	4
18	18	Trimpots	4	4	5	5
10	19	No	3	1	3	3
13	20	Yes, optional	4	3	4	2
12	21	No	3	3	3	3
12	22	No	3	3	3	3
10	23	No	2	3	2	3
13	24	LED	3	2	4	4
16	25	Yes, optional	4	4	5	3
15	26	Four plus four 'comments'	4	4	4	3
12	27	After one ear	3	3	3	3
16	28	Yes	4	4	4	4
15	29	Yes	4	4	3	4
16	30	One	3	5	5	3
12	31	No	3	3	3	3
14	32	Yes, in three frequency ranges	4	3	4	3
13	33	No	3	3	4	3
9	34	No	3	1	3	2
17	35	40W (60W peak)	5	4	4	4
12	36	No	3	3	3	3
15	37	15 presentations	4	3	4	4
17	38	Technician decides	4	4	5	4
14	39	Manual	4	4	3	3
17	40	Yes	4	5	4	4
18	41	Yes	4	5	5	4
10	42	Yes, optional	3	3	1	3
8	43	Yes	2	1	2	3
19	44	Excellent at high signal levels	5	5	4	5
		=	152	145	152	147
				= 596		
				$\bar{\bar{x}}$ = 149		
				$\bar{x}$ = 3.39		

*1=poor, 2=fair, 3=average, 4=good, 5=outstanding

Table B III

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the General Features of the TRACOR RA 410

Sum of Ratings	Feature Code	Description	A	B	C	D
13	1	250 to 8000 Hz	3	4	3	3
14	2	Yes	3	4	4	3
17	3	Choice	4	4	5	4
12	4	1000 Hz one ear	3	3	3	3
16	5	Minus 10 to 90 dB	5	4	5	2
13	6	Single pulse	3	3	4	3
14	7	One	3	4	4	3
14	8	Manual	3	4	4	3
14	9	.5 to 2 sec.	4	4	2	4
13	10	No	3	3	4	3
16	11	3 responses same level	4	5	4	3
10	12	7-10 minutes	3	1	3	3
12	13	Keyboard (numeric)	3	3	3	3
14	14	30 characters	3	3	4	4
13	15	Printer	4	3	3	3
11	16	Thermal	4	1	3	3
13	17	Yes (not modular)	3	3	4	3
18	18	Trimpots	4	4	5	5
10	19	No	3	1	3	3
13	20	Yes	4	2	4	3
12	21	No	3	3	3	3
12	22	No	3	3	3	3
10	23	No	2	3	2	3
13	24	LED	3	2	4	4
16	25	Yes	4	4	5	3
13	26	Three	3	3	4	3
12	27	Some at start, some at end	3	2	3	4
7	28	No	2	1	1	3
6	29	No	2	1	1	2
17	30	One	4	5	5	3
12	31	No	3	3	3	3
12	32	No	3	3	3	3
13	33	No	3	3	4	3
9	34	No	3	1	3	2
18	35	40W	5	4	5	4
12	36	No	3	3	3	3
--	37	--	-	-	-	-
17	38	Technician decides	4	4	5	4
17	39	Either manual or automatic	4	4	5	4
17	40	Yes	4	5	4	4
18	41	Yes	4	5	5	4
10	42	Yes, technician's option	3	3	1	3
8	43	Yes	2	1	2	3
8	44	Poor at high signal levels	2	1	3	2
		=	141	130	151	137
			= 559			
			$\bar{x}$ = 140			
			$\bar{x}$ = 3.18			

*1=poor, 2=fair, 3=average, 4=good, 5=outstanding

Table B IV

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the General Features of the ETC G.R.S.-1

Sum of Ratings	Feature Code	Description	A	B	C	D
14	1	500 to 8000 Hz	3	4	4	3
8	2	No	3	1	1	3
11	3	R/L	3	2	3	3
12	4	1000 Hz both ears	4	3	3	2
14	5	0 to 100 dB	3	3	4	4
14	6	Single pulse or 3 pulse train	3	3	5	3
14	7	One	3	4	4	3
14	8	Manual	3	4	4	3
12	9	No	3	2	4	3
13	10	No	3	3	4	3
14	11	3 responses same level	3	4	4	3
15	12	6-8 minutes	4	3	4	4
7	13	Keyboard optional peripheral	2	1	3	1
--	14	---	-	-	-	-
13	15	Printer	4	3	3	3
9	16	Thermal, peripheral	3	1	3	2
9	17	No	2	3	2	2
7	18	Firmware	3	1	1	2
18	19	Yes	5	5	4	4
13	20	Optional	4	3	4	2
12	21	No	3	3	3	3
12	22	No	3	3	3	3
12	23	Yes	5	1	3	3
13	24	LED	3	2	4	4
16	25	Yes	4	4	5	3
18	26	Seven	5	5	4	4
19	27	Immediate	5	5	4	5
17	28	Yes	4	5	4	4
16	29	Yes	4	5	3	4
16	30	One	3	5	5	3
12	31	Yes, option	3	3	3	3
11	32	Yes, option	3	3	2	3
11	33	Yes, option	3	3	2	3
13	34	Yes, option	4	3	3	3
--	35	---	-	-	-	-
12	36	No	3	3	3	3
12	37	75 sec.	3	3	3	3
17	38	Automatic	4	5	5	3
14	39	Manual	4	4	3	3
16	40	Yes	3	5	4	4
18	41	Yes, semi-automatic	5	5	5	3
13	42	No	3	3	4	3
16	43	No	3	5	5	3
16	44	Good at high signal levels	4	4	4	4
		=	145	140	148	130
				= 563		
				$\bar{x}$ = 141		
				$\bar{x}$ = 3.2		

*1=poor, 2=fair, 3=average, 4=good, 5=outstanding

Table B V

Ratings* Assigned by Each of Four Raters (A,B,C,D) to the General Features of the ACA 500 I

Sum of Ratings	Feature Code	Description	Ratings A	B	C	D
14	1	500 to 8000 Hz	3	4	4	3
8	2	No	3	1	1	3
10	3	L/R	3	2	3	2
12	4	1000 Hz one ear	3	3	3	3
13	5	0 to 95 dB	3	3	4	3
12	6	Variable, two or three	3	3	4	2
8	7	Several	2	1	2	3
8	8	Manual, tone count and variation	2	1	2	3
12	9	No	3	2	4	3
12	10	No	3	2	4	3
5	11	Generally 2 responses at same level (often only 1)	2	1	1	1
14	12	6 to 8 min.	3	3	4	4
12	13	Keyboard, numeric	3	3	3	3
11	14	63 characters	3	3	1	4
13	15	Printer	4	3	3	3
11	16	Impact, ink ribbon	2	4	3	2
7	17	No	2	2	1	2
6	18	Firmware	2	1	1	2
10	19	No	3	1	3	3
13	20	Yes	4	2	4	3
12	21	No	3	3	3	3
12	22	Yes	4	2	3	3
10	23	No	2	3	2	3
10	24	NIXIE	3	1	3	3
16	25	Yes	4	4	5	3
13	26	Three	3	3	4	3
14	27	Immediate	3	3	3	5
7	28	No	2	1	1	3
14	29	Yes	3	4	3	4
6	30	Up to 50	2	1	1	2
11	31	Yes	3	1	4	3
10	32	Yes	3	1	3	3
9	33	Yes	3	1	2	3
15	34	Yes	4	4	3	4
8	35	200W	2	1	2	3
12	36	No	3	3	3	3
6	37	Indefinite	2	1	1	2
5	38	Must restart test	2	1	1	1
14	39	Manual or automatic	3	4	3	4
16	40	Yes	4	5	3	4
17	41	Yes	4	5	4	4
14	42	No	3	3	5	3
8	43	Yes	2	1	2	3
7	44	Poor at high signal levels	1	1	3	2
		=	124	102	122	129
			= 477			
			$\bar{x}$ = 119			
			$\bar{x}$ = 2.70			

*1=poor, 2=fair, 3= average, 4=good, 5=outstanding

Appendix C

Additional Unrated Features of the Four Units
Subjected to Exploratory Assessment

Table C I

Instrument: MAICO MA26

Multiple pulse timing	200/200 msec.
Threshold logic	modified Hughson-Westlake
Rise/decay times	40/80 msec.
Over-shoot	0
Frequency accuracy	± 1%
Maximum harmonic distortion	2%
Maximum number of subjects tested	one
Headphone type	TDH-39P/10 ohm
Peripheral storage at site	none
Audiometer housing	metal

Table C II

Instrument: TRACOR RA 410

Threshold logic	modified Hughson-Westlake
Rise/decay times	60/30 msec.
Frequency accuracy	less than 2%
Maximum harmonic distortion	less than 40 dB
Maximum number of subjects tested	one
Headphone type	TDH-39/10 ohm
Audiometer housing	plastic

Table C III

Instrument: ETC G.R.S.-1

Multiple pulse timing--------------	200/200 msec.
Single pulse timing----------------	1200 msec.
Threshold logic--------------------	modified Hughson-Westlake
Cross talk-------------------------	greater than 100 dB
Frequency accuracy-----------------	2% or less
Maximum harmonic distortion--------	greater than 50 dB down
Amplitude linearity----------------	maximum 2 dB or less
S/N ratio--------------------------	greater than 100 dB down
Maximum number of subjects tested--	one
Headphone type---------------------	TDH-39P/10 ohm
Peripheral storage at site---------	optional cassette in T.I. terminal
Audiometer housing-----------------	metal

Table C IV

Instrument: ACA Besserman 500 I

Threshold logic--------------------	modified Hughson-Westlake
Frequency accuracy-----------------	$\pm$ 3%
Maximum number of subjects tested--	one
Headphone type---------------------	TDH-39/100 ohm
Peripheral storage at site---------	none (optional peripheral tape unit)
Audiometer housing-----------------	metal

Appendix D

Features and Specifications
of Microprocessor-Controlled Audiometers not Evaluated

Table D I

Instrument: AMS (uses ARJ4C/AD)

Test frequencies	500 to 8000 Hz
Delete frequency capability	no
Ear sequence	technician's choice
Decibel range	-10 to 90
Number of test paradigms	one
Type of test paradigm	Bekesy tracking procedure
Variable inter-stimulus interval	no
Variable stimulus duration	no
Threshold criterion	tracking procedure
Test time per subject	7 ∓ 2%
ID information entry by	keyboard, alpha-numeric
Hard copy unit	printer peripheral
Integral printer	no
Calibration	trimpots
Automatic slowing of test	no
RS-232	yes
GPIB	no
TTY	no (has modem)
Intercom	no
Type of display	CRT
Test pause capability	yes
Number of error warnings	none
Auditory signal to technician	no
Visual signal to technician	no
Audiogram storage capacity (internal)	one
Classifies loss	yes
Pure tone average computation	yes
AAOO computation	yes
Significant threshold shift computation	yes
CRT terminal	yes
Maximum time allowed per frequency	30 sec.
Re-test of missed frequencies	at discretion of technician
Re-test mode	" " " "
Automatic printing of serial number	yes
Manual test capability	no
Prints out all subject responses	yes, tracing
Multi-function keys	yes
Multiple pulse timing	2.5 Hz, 50% duty cycle
Continuous tone	yes
Threshold logic	Bekesy tracking
Rise/decay times	20-100 mx/5-100 ms
Cross talk	-70 dB
Over-shoot	less than 0.1 dB
Frequency accuracy	per ANSI-1969
Harmonic distortion	-30 dB below fundamental
Maximum # of subjects tested	one
Headphone type	MX-41/AR cushions, TDH-39, 100 ohms
Peripheral storage at site	integral cassette
Audiometer housing	plastic

Table D II

Instrument: DANA Model DA 211-A

Test frequencies-------------------	250-8000 Hz (no 3000 Hz)
Delete frequency capability--------	yes
Ear sequence-----------------------	technician's choice
Decibel range----------------------	0 to 100 dB automatic,-10 to 100 manual
Number of signal pulses------------	one
Number of test paradigms-----------	one
Type of test paradigm--------------	manual
Variable inter-stimulus interval---	no
Variable stimulus duration---------	no
ID information entry by------------	none
Hard copy unit---------------------	printer
Integral printer-------------------	no
Automatic slowing of test----------	no
RS-232-----------------------------	yes
Type of display--------------------	LED
Test pause capability--------------	yes
Auditory signal to technician------	no
Visual signal to technician--------	yes
Audiogram storage capacity(internal)	one
Classifies loss--------------------	no
Pure tone average computation------	no
AAOO computation-------------------	no
Significant threshold shift computation----------------------------	no
Power consumption------------------	80W
CRT terminal-----------------------	no
Re-test of missed frequencies------	technician's choice
Re-test mode-----------------------	manual
Automatic printing of serial no.---	yes
Manual test capability-------------	yes
Single pulse timing----------------	2000/2000 msec.
Threshold logic--------------------	descending 5 dB increments
Rise/decay times-------------------	25 msec.
Frequency accuracy-----------------	± 3%
Maximum harmonic distortion--------	less than minus 26 dB
Amplitude linearity----------------	electronic attenuator
S/N ratio--------------------------	greater than 60 dB
Maximum number of subjects tested--	one
Headphone type---------------------	TDH-49/10
Peripheral storage at site---------	punched tape
Audiometer housing-----------------	metal

Table D III

Instrument: Demlar

Test frequencies----------------------	250 to 8000 Hz
Delete frequency capability---------	no
Ear sequence------------------------	technician selects
Repeat frequencies------------------	1000 Hz right ear
Decibel range-----------------------	minus 10 to 90 dB
Number of signal pulses-------------	pulse train
Number of test paradigms------------	three
Type of test paradigm---------------	manual, automated manual and self-recording Bekesy tracking procedure
Variable inter-stimulus interval----	no
Variable stimulus duration----------	no
Threshold criterion-----------------	3/3
Test time per subject---------------	30 sec per frequency(in Bekesy mode)
ID information entry by-------------	keyboard
ID information capacity-------------	20-49
Integral printer--------------------	yes
Calibration-------------------------	trimpot
Automatic slowing of test-----------	no
RS-232------------------------------	yes
GPIB--------------------------------	no
TTY---------------------------------	yes
Intercom----------------------------	yes
Type of display---------------------	LED
Test pause capability---------------	no
Number of error warnings------------	eight
When error warning------------------	end of test
Auditory signal to technician-------	yes
Visual signal to technician---------	no
Audiogram storage capacity(internal)	400 (has integral cassette)
Classifies loss---------------------	yes
Pure tone average computation-------	yes
AAOO computation--------------------	yes
Significant threshold shift computation--------------------------	no
CRT terminal------------------------	no
Maximum time allowed per frequency--	30 sec.
Re-test of missed frequencies-------	technician decides
Re-test mode------------------------	manual
Automatic printing of serial number-	yes
Manual test capability--------------	yes
Prints out all subject responses----	no
Multi-function keys-----------------	no
Signal-to-noise ratio---------------	unit inoperative at demonstration
Multiple pulse timing---------------	200/100 msec.
Single pulse timing-----------------	2000/1000 msec.
Threshold logic---------------------	modified Hughson-Westlake
Frequency accuracy------------------	less than 2%
Maximum harmonic distortion---------	less than 2%
S/N ratio---------------------------	down 65 dB
Maximum number of subjects tested---	four
Headphone type----------------------	TDH/49P/10 ohm
Peripheral storage at site----------	cassette, integral
Audiometer housing------------------	plastic

Table D IV

Instrument: Monitor Ototest 6000

Test frequencies--------------------	500 to 8000 Hz
Delete frequency capability---------	no
Ear sequence------------------------	L/R
Repeat frequencies------------------	1000 Hz right ear
Decibel range-----------------------	0 to 90 dB
Number of signal pulses-------------	three pulses
Number of test paradigms------------	one
Type of test paradigm---------------	manual
Variable inter-stimulus interval----	yes, 2-4 sec.
Variable stimulus duration----------	no
Threshold criterion-----------------	2/3 x 2/4
ID information entry by-------------	keyboard
ID information capacity-------------	31 per subject (6-man unit)
Hard copy unit----------------------	printer
Type of printer---------------------	thermal, TI silent 700
Integral printer--------------------	no
Calibration-------------------------	firmware
Automatic slowing of test-----------	no
RS-232------------------------------	yes
Intercom----------------------------	no
Type of display---------------------	CRT
Test pause capability---------------	no
Number of error warnings------------	no (tally)
Auditory signal to technician-------	no
Visual signal to technician---------	yes
Audiogram storage capacity(internal)	6
Classifies loss---------------------	no
Pure tone average computation-------	no
AAOO computation--------------------	no
Significant threshold shift computation-----------------------------	no
CRT terminal------------------------	yes
Maximum time allowed per frequency--	16 presentations
Re-test of missed frequencies-------	automatic
Re-test mode------------------------	automatic
Automatic printing of serial number-	no
Manual test capability--------------	no
Prints out all subject responses----	no
Multi-function keys-----------------	no
Signal-to-noise ratio---------------	very poor, audible click at each tone presentation
Multiple pulse timing---------------	250/50 msec.
Threshold logic---------------------	modified Hughson-Westlake
Rise/decay times--------------------	50 msec.
Over-shoot--------------------------	0
Frequency accuracy------------------	± 1%
Maximum harmonic distortion---------	2% maximum
Maximum number of subjects tested---	six
Headphone type----------------------	TDH-39/10 ohm
Peripheral storage at site----------	cassette in T.I. terminal
Audiometer housing------------------	metal

Appendix E

Test Durations During Automated and Manual Testing

Table E I

Test Duration (Minutes) for Normal Hearing and Sensorineural Hearing Loss Subjects for Automated and Manual Testing

MCA	Automated Pulse*	Automated Std**	Manual	Difference
		NORMALS		
MAICO 6 Freq.	6.2	---	6.1	+0.1
TRACOR				
6 Freq.	---	6.8	6.6	+0.2
7 Freq.	---	7.9	7.7	+0.2
ETC				
6 Freq.	---	5.2	5.6	-0.4
	5.0	---	6.1	-1.1
7 Freq.	---	6.0	6.6	-0.6
	5.8	---	7.1	-1.3
ACA				
6 Freq.	5.0	---	5.6	-0.6
7 Freq.	5.8	---	6.6	-0.8
		SENSORINEURAL		
MAICO 6 Freq.	8.0	---	6.9	+1.1
TRACOR				
6 Freq.	---	7.0	6.9	+0.1
7 Freq.	---	8.2	8.0	+0.2
ETC				
6 Freq.	---	5.6	6.4	-0.8
	5.5	---	6.7	-1.2
7 Freq.	---	6.6	7.4	-0.8
	6.4	---	7.8	-1.4
ACA				
6 Freq.	6.0	---	6.4	-0.4
7 Freq.	7.0	---	7.5	-0.5

*Presentation of two to three pulses per stimulus event period.
** Presentation of a single tone pulse per stimulus event period.

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Past attempts to establish reliable group hearing test procedures have been unsuccessful, as has the present-day application of group self-recording audiometry. Recent occupational health surveys at naval industrial facilities have indicated that a large percentage of the audiograms currently being obtained on group units are invalid. Recently developed microprocessor-controlled audiometers may serve to minimize or eliminate this serious problem.

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Laboratory and field assessments conducted on four microprocessor-controlled audiometers (non-group) indicate they: 1) produce hearing threshold levels comparable to those obtained with manual audiometers and within the same time frame; 2) employ programmable threshold seeking logic, thus ensuring testing consistency at any location; 3) can be programmed to provide fault detection which makes it difficult for individuals to falsify the audiometric data; and 4) provide digitized output information that can be transmitted to a larger computer, either directly or through the generation of onboard data tapes. Subsequent to the exploratory assessment of the four units, tentative performance specifications have been identified for a microprocessor-controlled audiometer for use in Navy hearing conservation programs.

Field testing of a group microprocessor-controlled audiometer is recommended prior to establishing final Navy performance specifications for such an instrument.